Pairing and (9/2)n configuration in the neutron-rich Ni isotopes

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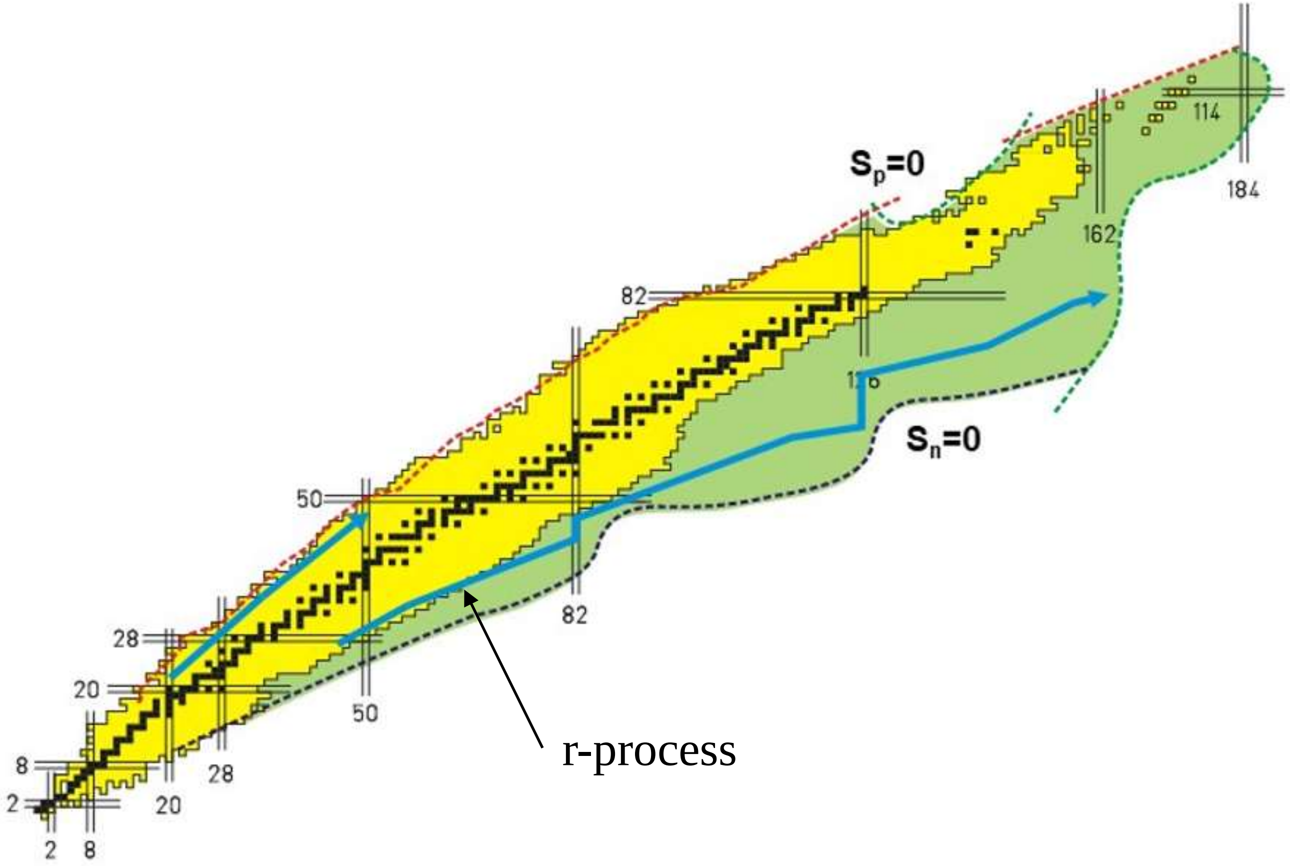
Contents

Introduction, research area

1. Nuclear shell structure (nuclei are in the island of inversion)
2. Astrophysical investigations (r-process starts with the field of studied isotopes)



Goals

1. Calculation of spectra of low-lying excited states calculations in the δ-potential approximation with seniority scheme to describe states with a larger number of unpaired nucleons
2. Verification of this model approach by comparing the results obtained with experimental data
3. Study of $\nu = 4$ multiplet splitting and order of GSM states on the 2^{+} $(\nu = 2)$ state

Ground state multiplet (GSM)

GSM can be estimated in the δ-force approximation

$V(r_1, r_2) = -V_0 \cdot \delta(r_1 - r_2)$

The ratio for the relative shift of the state with total moment J

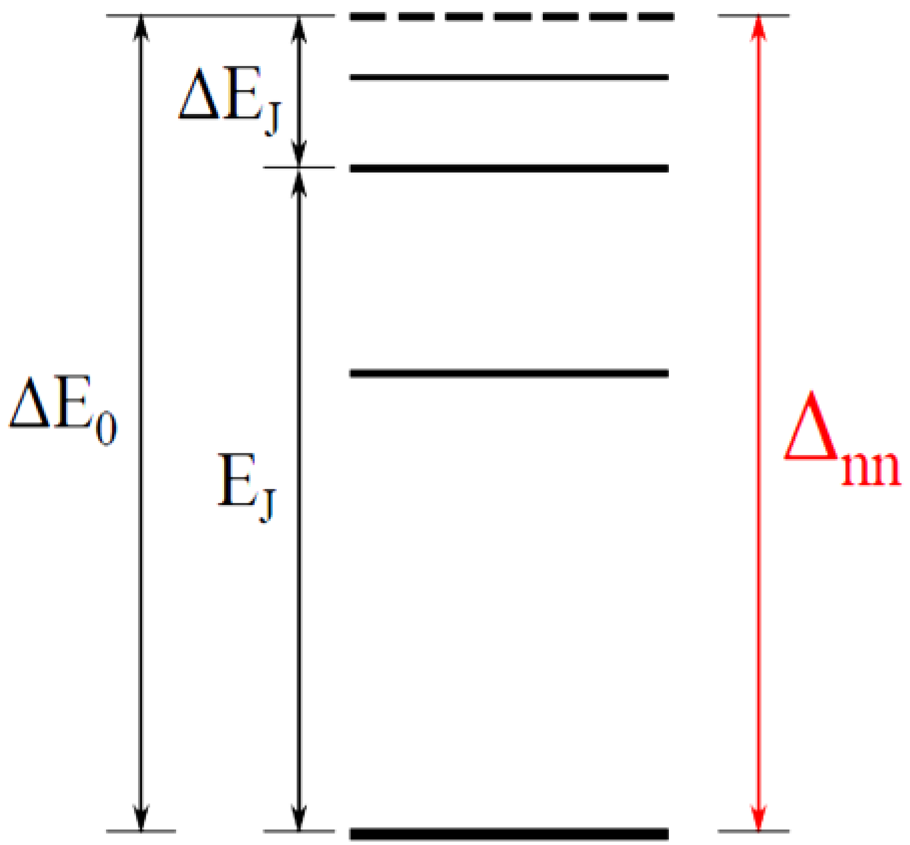
$$\frac{\Delta E_J}{\Delta E_0} = (2j+1)\begin{pmatrix} j & j & J \\ \frac{1}{2} & -\frac{1}{2} & 0 \end{pmatrix}^2$$

Energy of all levels of the multiplet

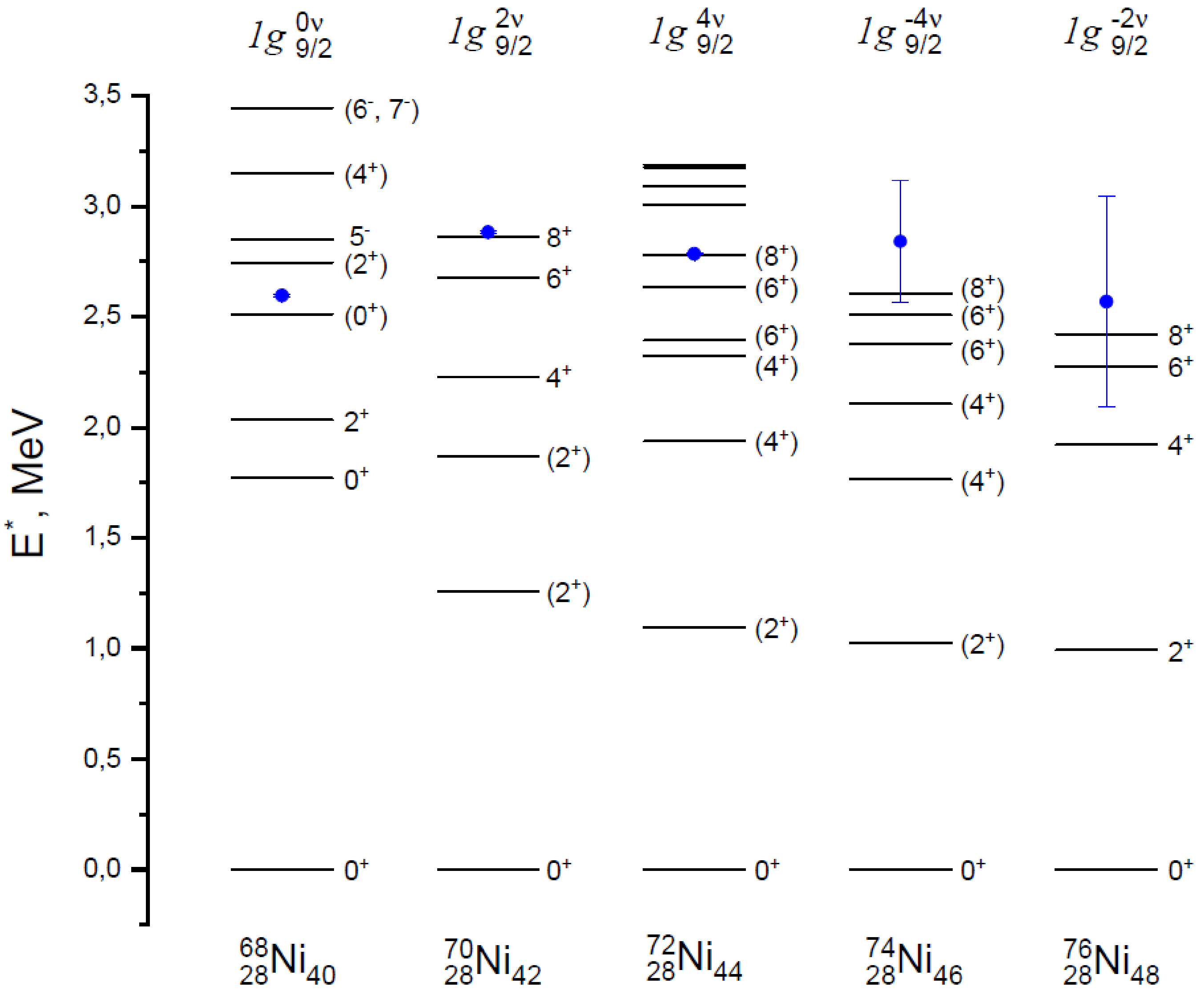
$$E_J = \Delta_{NN}\left(1 - \frac{\Delta E_J}{\Delta E_0}\right)$$

The splitting is determined by the mass relation

$$\Delta_{nn}^{(4)}(N) = \frac{(-1)^N}{2}\left[-S_n(N-1) + 2S_n(N) - S_n(N+1)\right]$$



Experimental spectra of even isotopes $^{68-76}$Ni. The dots indicate the value of the *nn*-pairing energy $\Delta_{nn}^{(4)}$ in Ni. The shell configuration is written above.



Seniority scheme

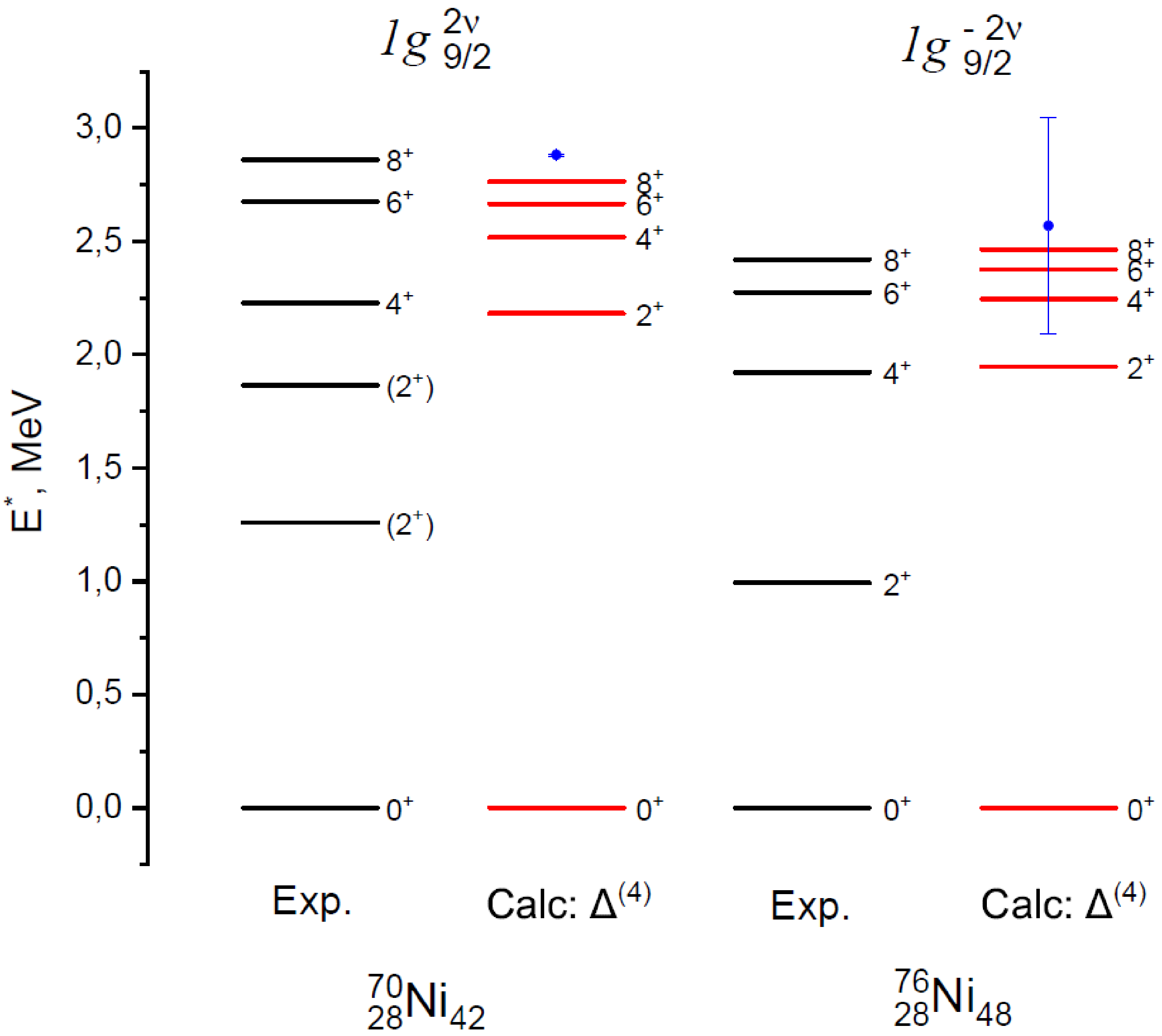
If there are known wave functions and values of the energy of states of two nucleons on a subshell, the wave functions and energies of states of a system with three external nucleons can be found as combinations of the wave functions of two nucleons and a third nucleon:

$$E(J_3) = \sum_{J_2} [(jj)J_2 j J_3 | \}j^3 J_3]^2 E(J_2),$$

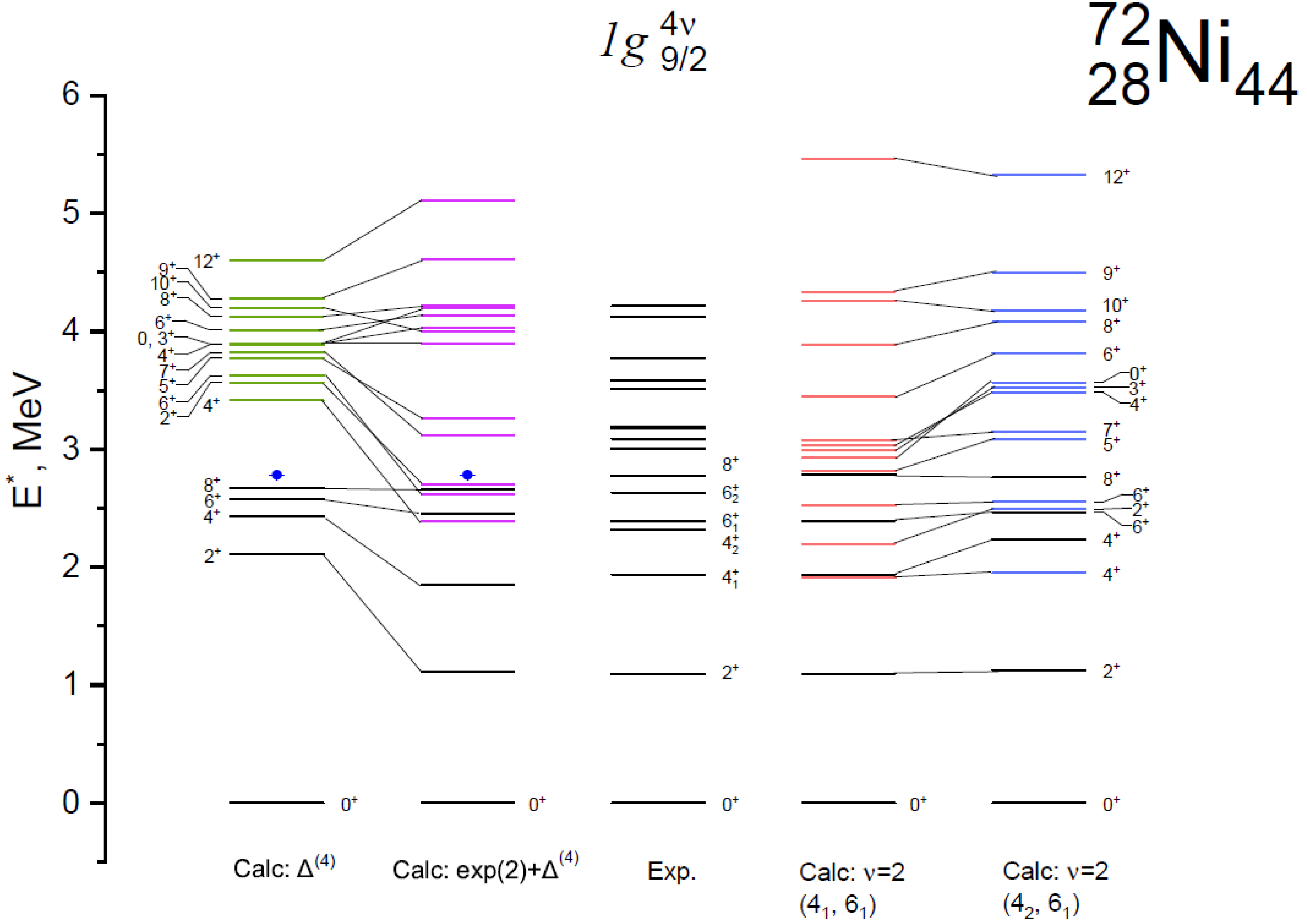
$[(jj)J_2 j J_3 | \}j^3 J_3]$- parentage coefficient

v	Total moment J
0	0
1	$\frac{9}{2}$
2	2, 4, 6, 8
3	$\frac{3}{2}, \frac{5}{2}, \frac{7}{2}, \frac{9}{2}, \frac{11}{2}, \frac{13}{2}, \frac{15}{2}, \frac{17}{2}, \frac{21}{2}$
4	$0, 2, 3, 4^2, 5, 6^2, 7, 8, 9, 10, 12$
5	$\frac{1}{2}, \frac{5}{2}, \frac{7}{2}, \frac{9}{2}, \frac{11}{2}, \frac{13}{2}, \frac{15}{2}, \frac{17}{2}, \frac{19}{2}, \frac{25}{2}$

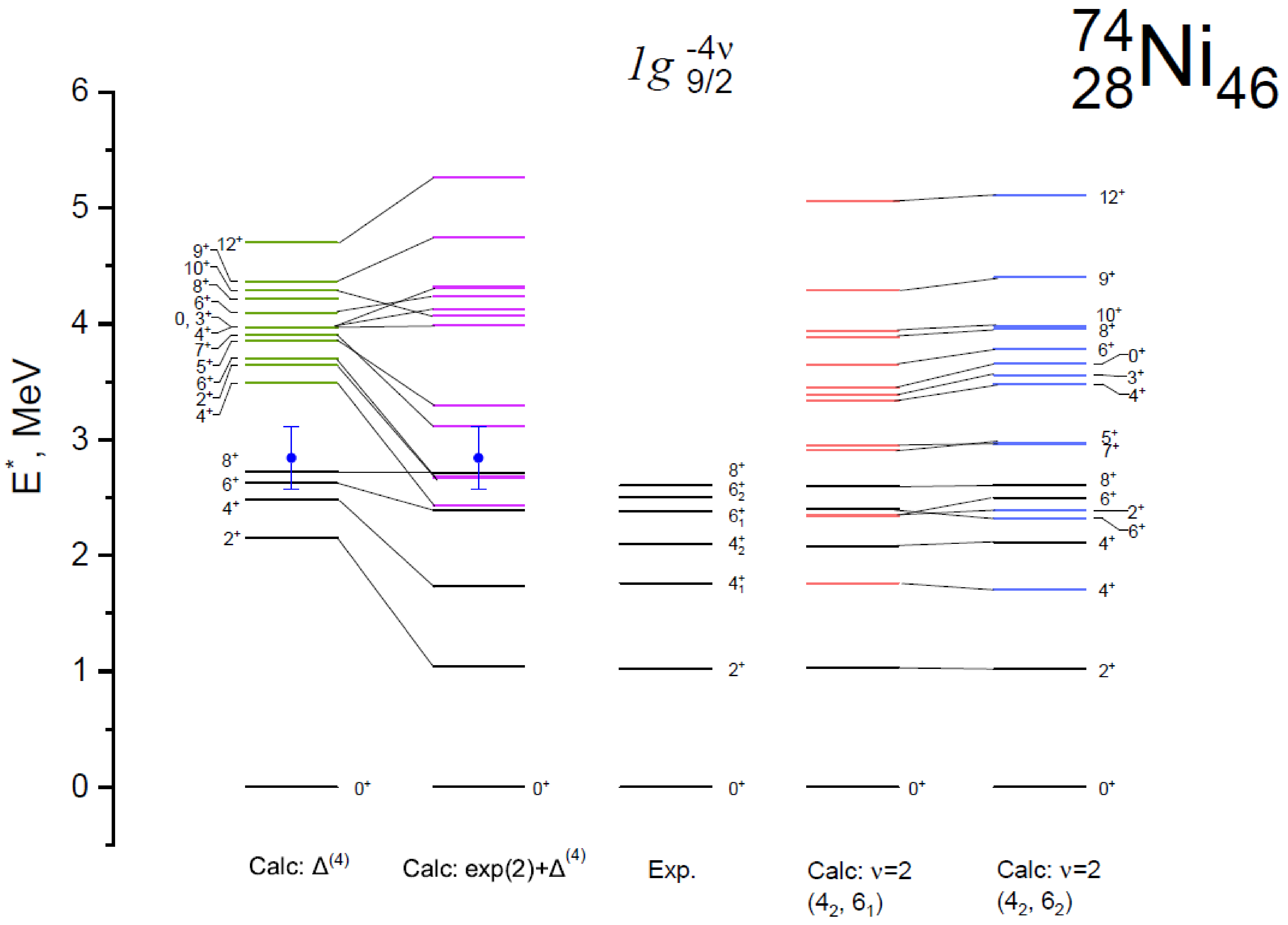
Results



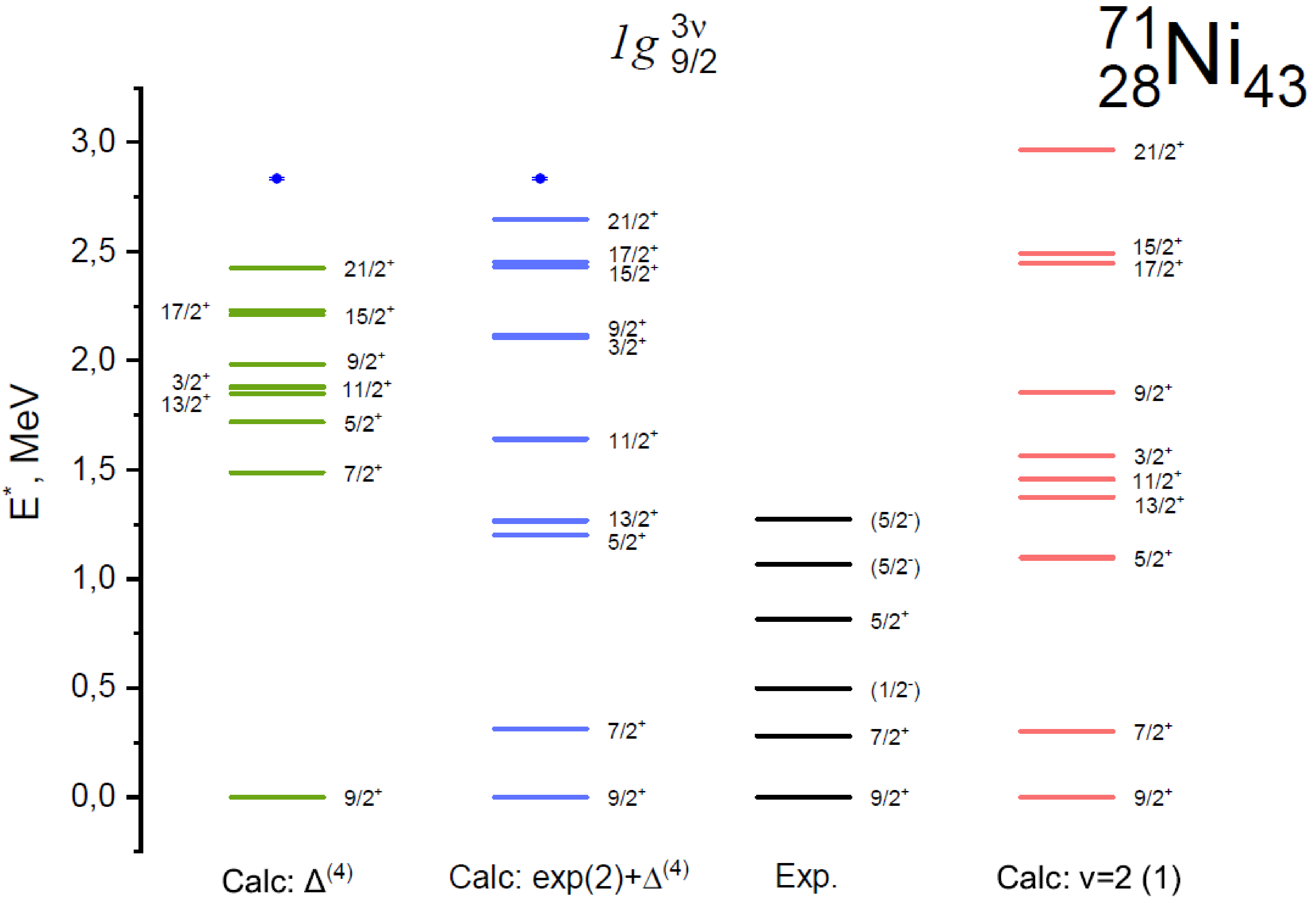
$1g_{9/2}^{2\nu}$
$1g_{9/2}^{-2\nu}$
E*, MeV
3,0
2,5
2,0
1,5
1,0
0,5
0,0
8+
6+
4+
(2+)
(2+)
0+
8+
6+
4+
2+
0+
8+
6+
4+
2+
0+
8+
6+
4+
2+
0+
Exp.
Calc: Δ(4)
Exp.
Calc: Δ(4)
$^{70}_{28}Ni_{42}$
$^{76}_{28}Ni_{48}$



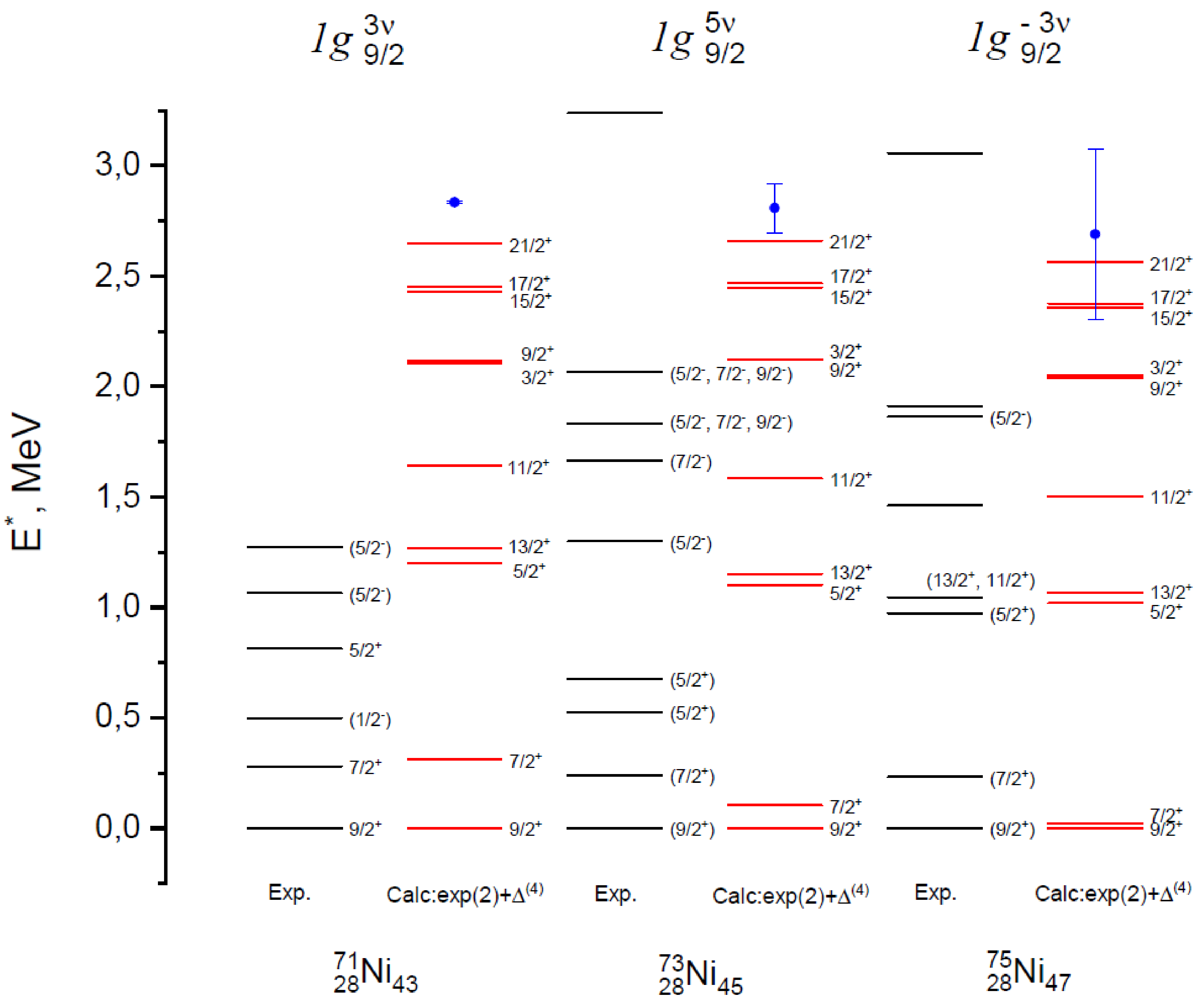
$1g^{4\nu}_{9/2}$
$^{72}_{28}Ni_{44}$
E*, MeV
0
1
2
3
4
5
6
Calc: Δ(4)
Calc: exp(2)+Δ(4)
Exp.
Calc: ν=2 (4₁, 6₁)
Calc: ν=2 (4₂, 6₁)



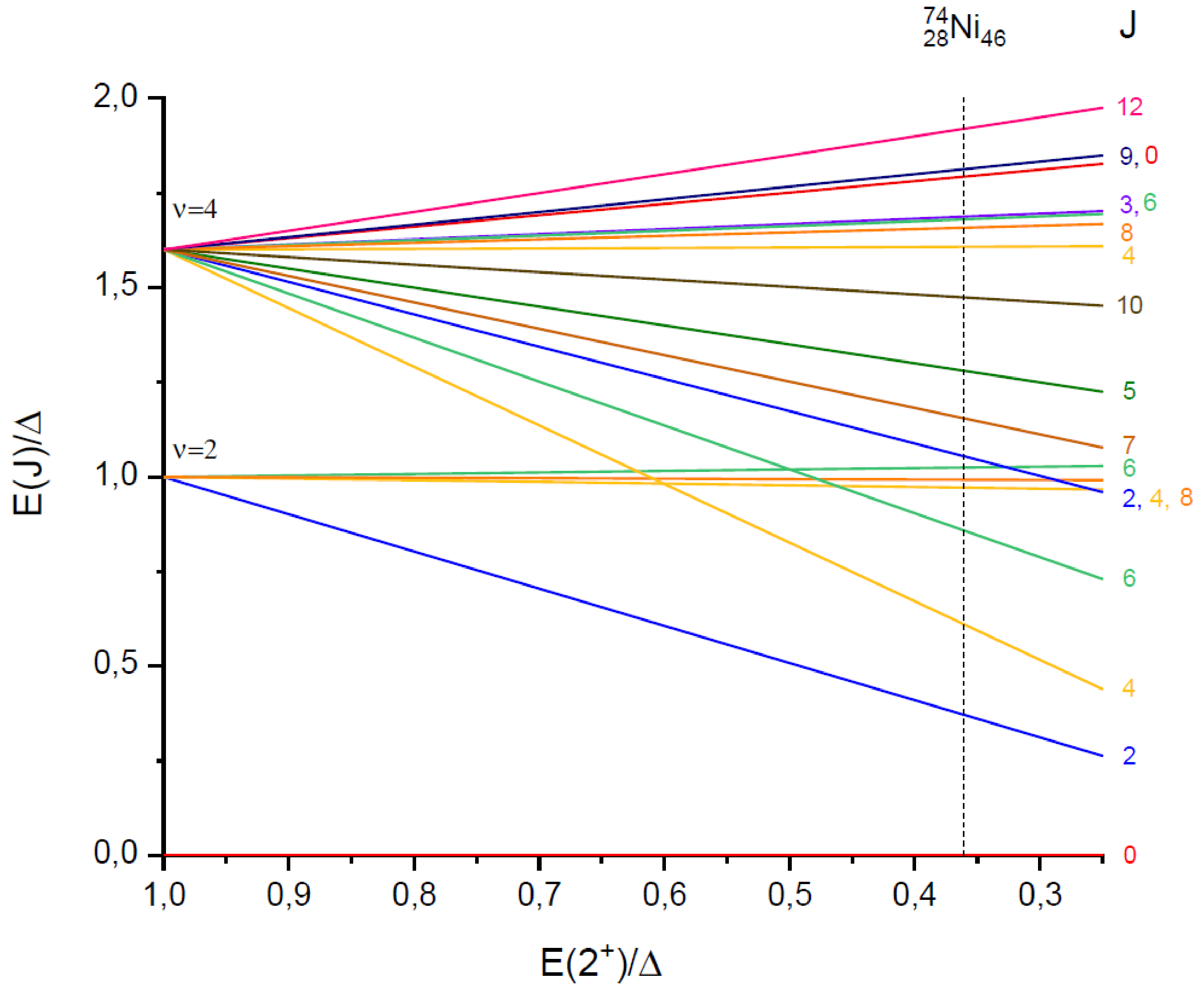
$^{74}_{28}Ni_{46}$
$1g_{9/2}^{-4\nu}$
E*, MeV
Calc: Δ(4)
Calc: exp(2)+Δ(4)
Exp.
Calc: ν=2 (4₂, 6₁)
Calc: ν=2 (4₂, 6₂)



$1g^{3\nu}_{9/2}$
$^{71}_{28}Ni_{43}$
E*, MeV
3,0
2,5
2,0
1,5
1,0
0,5
0,0
21/2+
17/2+
15/2+
9/2+
3/2+
11/2+
13/2+
5/2+
7/2+
9/2+
21/2+
17/2+
15/2+
9/2+
3/2+
11/2+
13/2+
5/2+
7/2+
9/2+
(5/2-)
(5/2-)
5/2+
(1/2-)
7/2+
9/2+
21/2+
15/2+
17/2+
9/2+
3/2+
11/2+
13/2+
5/2+
7/2+
9/2+
Calc: Δ(4)
Calc: exp(2)+Δ(4)
Exp.
Calc: v=2 (1)



1g 3ν 9/2
1g 5ν 9/2
1g - 3ν 9/2
E*, MeV
3,0
2,5
2,0
1,5
1,0
0,5
0,0
Exp.
Calc:exp(2)+Δ(4)
71 28 Ni 43
73 28 Ni 45
75 28 Ni 47
(5/2-)
5/2+
(1/2-)
7/2+
9/2+
21/2+
17/2+
15/2+
3/2+
11/2+
13/2+
(5/2-, 7/2-, 9/2-)
(7/2-)
(5/2+)
(7/2+)
(9/2+)
(13/2+, 11/2+)

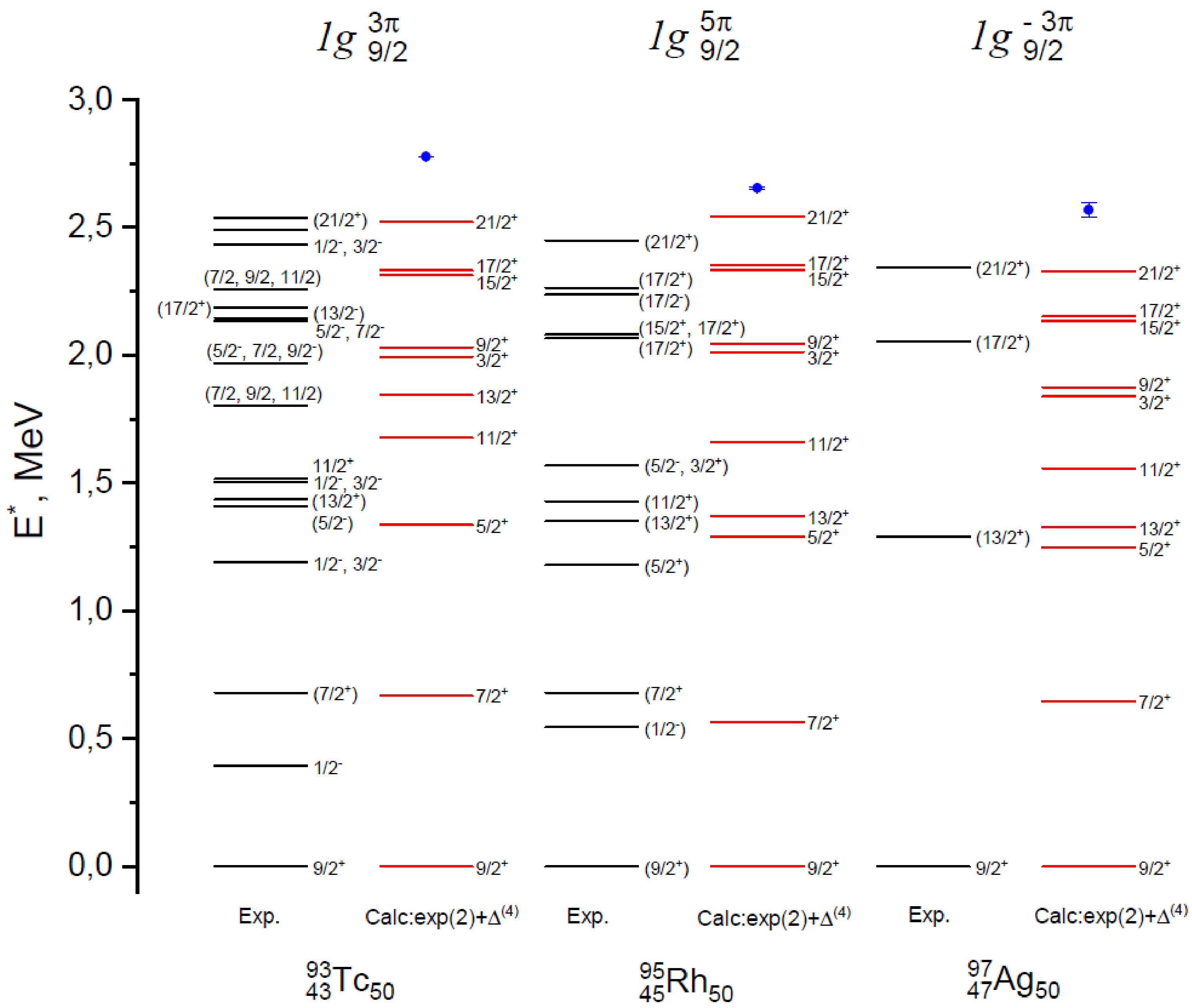


Seniority spectra $\nu = 4$ depending on the $2^+(\nu = 2)$ energy .

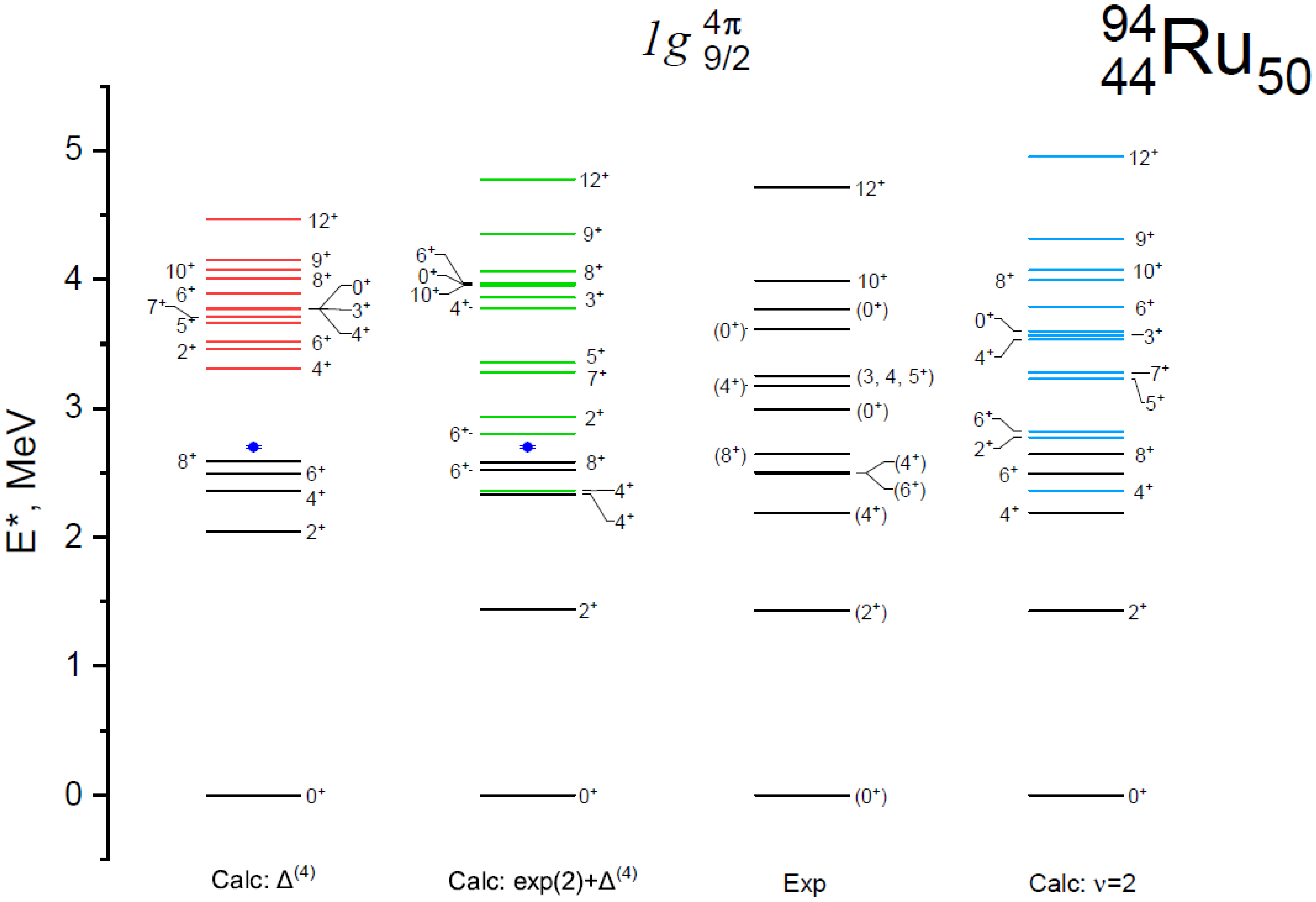
Conclusions

1. We considered the GSM forming in neutron-rich nickel isotopes $^{70-76}$Ni, which are of great interest from the point of view of the shell structure and astrophysical phenomena.
2. Splitting of GSM in isotopes under study can be described based on mass relations. In this case, even nuclei with an error of no more than 0.1 MeV reproduce the states $J^{\pi} = 6^{+}, 8^{+}$ $(\nu = 2)$ and states $J^{\pi} = 4^{+}$ $(\nu = 2)$ reproduced with an error of no more than 0.5 MeV.
3. It is shown that the approximation of delta interaction is not sufficient to reproduce the energy of 2^{+} $(\nu = 2)$.
4. It is shown that, in a number of isotopes under study, a particularly low position of the 2^{+} $(\nu = 2)$ leads to level inversion with the same J and different senority ν.

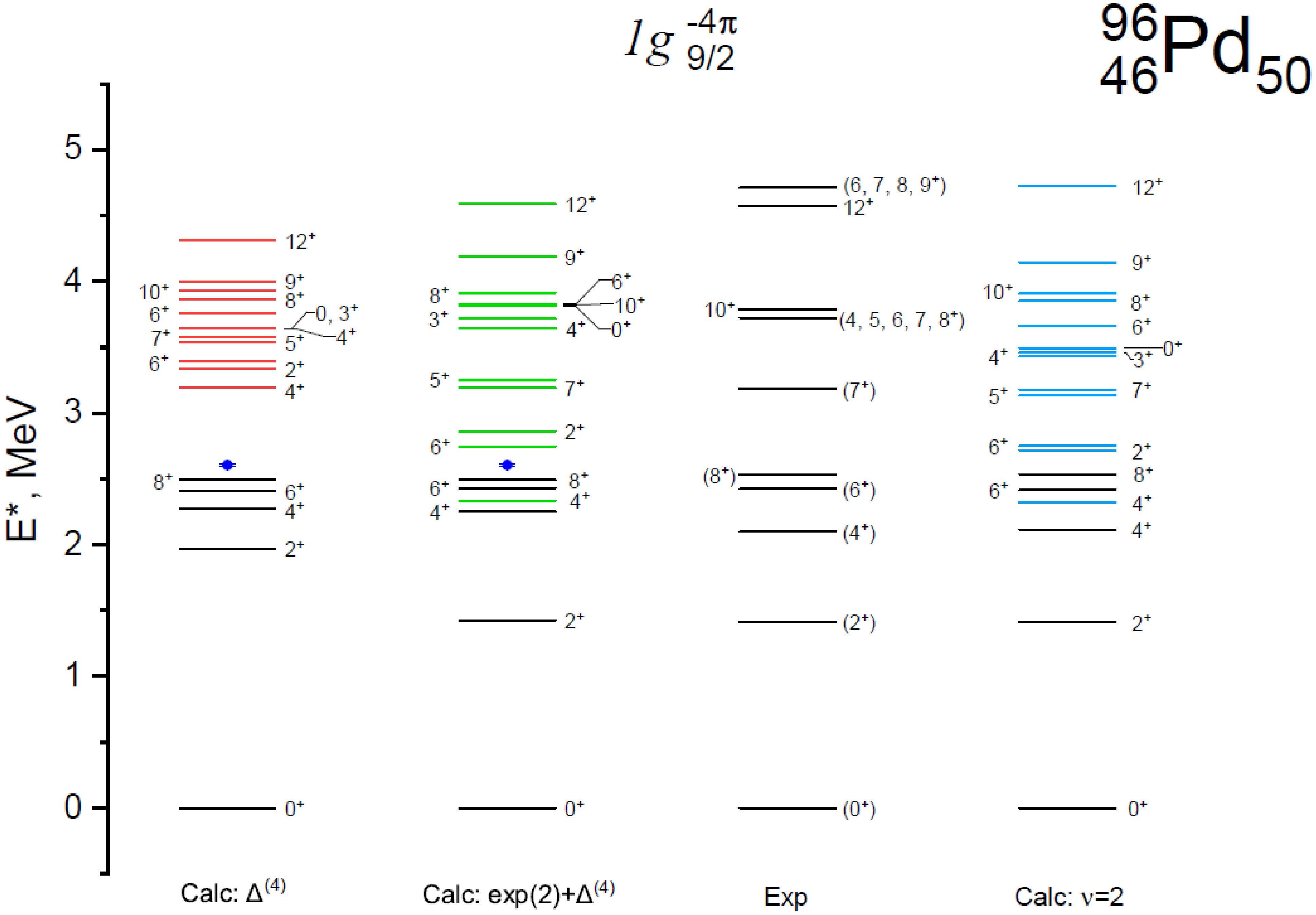
Thank you for attention!



1g 3π 9/2
1g 5π 9/2
1g - 3π 9/2
E*, MeV
3,0
2,5
2,0
1,5
1,0
0,5
0,0
(21/2+)
1/2-, 3/2-
(7/2, 9/2, 11/2)
(17/2+)
(13/2-)
5/2-, 7/2-
(5/2-, 7/2, 9/2-)
(7/2, 9/2, 11/2)
11/2+
1/2-, 3/2-
(13/2+)
(5/2-)
1/2-, 3/2-
(7/2+)
1/2-
9/2+
21/2+
17/2+
15/2+
9/2+
3/2+
13/2+
11/2+
5/2+
7/2+
9/2+
(21/2+)
(17/2+)
(17/2-)
(15/2+, 17/2+)
(17/2+)
(5/2-, 3/2+)
(11/2+)
(13/2+)
(5/2+)
(7/2+
(1/2-)
(9/2+)
21/2+
17/2+
15/2+
9/2+
3/2+
11/2+
13/2+
5/2+
7/2+
9/2+
(21/2+)
(17/2+)
(13/2+)
9/2+
21/2+
17/2+
15/2+
9/2+
3/2+
11/2+
13/2+
5/2+
7/2+
9/2+
Exp.
Calc:exp(2)+Δ(4)
Exp.
Calc:exp(2)+Δ(4)
Exp.
Calc:exp(2)+Δ(4)
93 43 Tc 50
95 45 Rh 50
97 47 Ag 50



$1g^{4\pi}_{9/2}$
$^{94}_{44}Ru_{50}$
E*, MeV
0
1
2
3
4
5
Calc: $\Delta^{(4)}$
Calc: exp(2)+$\Delta^{(4)}$
Exp
Calc: ν=2



1g -4π 9/2
96 46 Pd 50
E*, MeV
5
4
3
2
1
0
12+
10+
9+
8+
6+
0, 3+
7+
5+
4+
6+
2+
4+
8+
6+
4+
2+
0+
12+
9+
8+
6+
3+
10+
4+
0+
5+
7+
2+
6+
8+
6+
4+
4+
2+
0+
(6, 7, 8, 9+)
12+
10+
(4, 5, 6, 7, 8+)
(7+)
(8+)
(6+)
(4+)
(2+)
(0+)
12+
9+
10+
8+
6+
4+
0+
3+
5+
7+
6+
2+
8+
6+
4+
4+
2+
0+
Calc: Δ(4)
Calc: exp(2)+Δ(4)
Exp
Calc: ν=2